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Hydrogen Technology from Thermonuclear Research

Thermonuclear research began in the 1930s with the hypothesis that thermonuclear reactions are the energy sources of the Sun and stars. The nuclei of deuterium (heavy hydrogen) react more easily than the nuclei of normal hydrogen, and after Harold Urey separated deuterium in 1931, interest in the possibility of reacting deuterium increased. In 1942, Edward Teller began working on the possibility of initiating such reactions by means of an atomic explosion, but his initial conclusion was negative. Later the same year, he attended a conference on thermonuclear reactions where the group agreed that tritium (isotope of hydrogen) should be studied as well as deuterium and concluded that a thermonuclear explosion could be accomplished. The following year, plans for research on thermonuclear reactions were put aside at the newly formed Los Alamos laboratory to concentrate on uranium fission. Teller and a few others, however, continued their research.[1]

Until 1948, thermonuclear research received little support. Robert Oppenheimer, an early supporter, became opposed to further research on thermonuclear reactions after Hiroshima. Following the announcement that Russia had exploded an atomic bomb, the general advisory committee of the Atomic Energy Commission, chaired by Oppenheimer, recommended against proceeding with the development of a hydrogen bomb on technical, political, and moral grounds. The committee felt that the H-bomb was not yet technically feasible or economical and that lack of restrictions would mean high danger to civilization. This position was unpopular with many scientists at Los Alamos, where work continued, and with politicians, who recommended to President Truman that H-bomb development be initiated. The final catalyst appears to have been Klaus Fuchs's treachery; four days after he confessed to having given U.S. atomic secrets to the Russians, Truman directed that development of the H-bomb start.

With the presidential go-ahead in January 1950, Teller and associates at Los Alamos intensified their efforts to design a practical bomb and began preparations for some critical tests. Hydrogen liquefiers were needed for these, and Herrick L. Johnston of Ohio State University became a key figure in setting up and operating the equipment.

Johnston's New Career

The announcement that the U.S. would proceed with the H-bomb had special interest for Professor Johnston; he saw it as a golden opportunity to capitalize on his position as an authority on large-scale hydrogen liquefaction and associated equipment.[2]

Whether Johnston realized that this new opportunity would eventually take him completely away from his academic career is a matter of conjecture. His colleagues knew that he harbored a long-time disappointment over what he considered a lack of sufficient recognition in the scientific community.[3] Perhaps some of this feeling was associated with his earlier work on deuterium. His preceptor, William Giauque, had been awarded the 1949 Nobel chemistry prize for his achievements in low-temperature physics, and Giauque had generously credited Johnston with significant contributions in the description of the prize-winning work.[4] Whatever his reasoning, Johnston resolved to seek greater compensation for his expert knowledge of cryogenics. The hydrogen bomb development provided this opportunity and he seized it. From then on, Johnston gave less attention to science and education and more to developing a business in cryogenics equipment. By 1954 the metamorphosis was complete, but during the crucial 1950–1954 period, he simultaneously pursued three careers—scientist, educator, and businessman—all involved liquid hydrogen.

Johnston was colorful, unconventional, controversial; it was difficult for those who came in contact with him to remain neutral about him. To aspiring undergraduates, he was a person who made or broke them, for a good grade in his tough thermodynamics course was required for continuing a career in chemistry.[5] To graduate students, post-doctoral fellows, and his peers, Johnston was a first-class preceptor and scholar, a man of great inspiration and integrity.[6] To university officials, he was a mixed blessing; his contracts brought equipment, staff, and prestige; but his utter disregard for normal operating procedures brought endless problems.[7] To employees, he was a paternalistic and high-handed autocrat, impatient and demanding, who would, and did, fire a person at the slightest provocation.[8] To business associates, he was a formidable competitor, capable of quick responses, low bids, and early delivery of his products.[9]

To Johnston, there was no problem that could not be solved and solved quickly. He demanded and got the best in equipment and services for himself and his people. He disdained normal administrative procedures and anything resembling bureaucracy infuriated him. He was often at odds with one official or another and never hesitated to go over their heads to appeal to higher authority. An unsung hero and loyal supporter of Johnston was Edward Mack, Jr., chairman of the department of chemistry at Ohio State from 1941 to 1955, who spent long hours sorting out and solving the endless problems that always seemed to surround the fast-moving Johnston and his activities.[10] In spite of the problems, Johnston's work was internationally recognized and many of his graduate students and assistants became prominent in the scientific community.*

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*One graduate student was Clyde Allen Hutchinson, professor of chemistry at the University of Chicago; a key assistant was David A. White, now chairman of the department of chemistry of the University of Pennsylvania; another assistant was Thor Rubin, professor of chemistry at OSU. The old War Research Building at OSU is now named the Johnston Building in his honor.

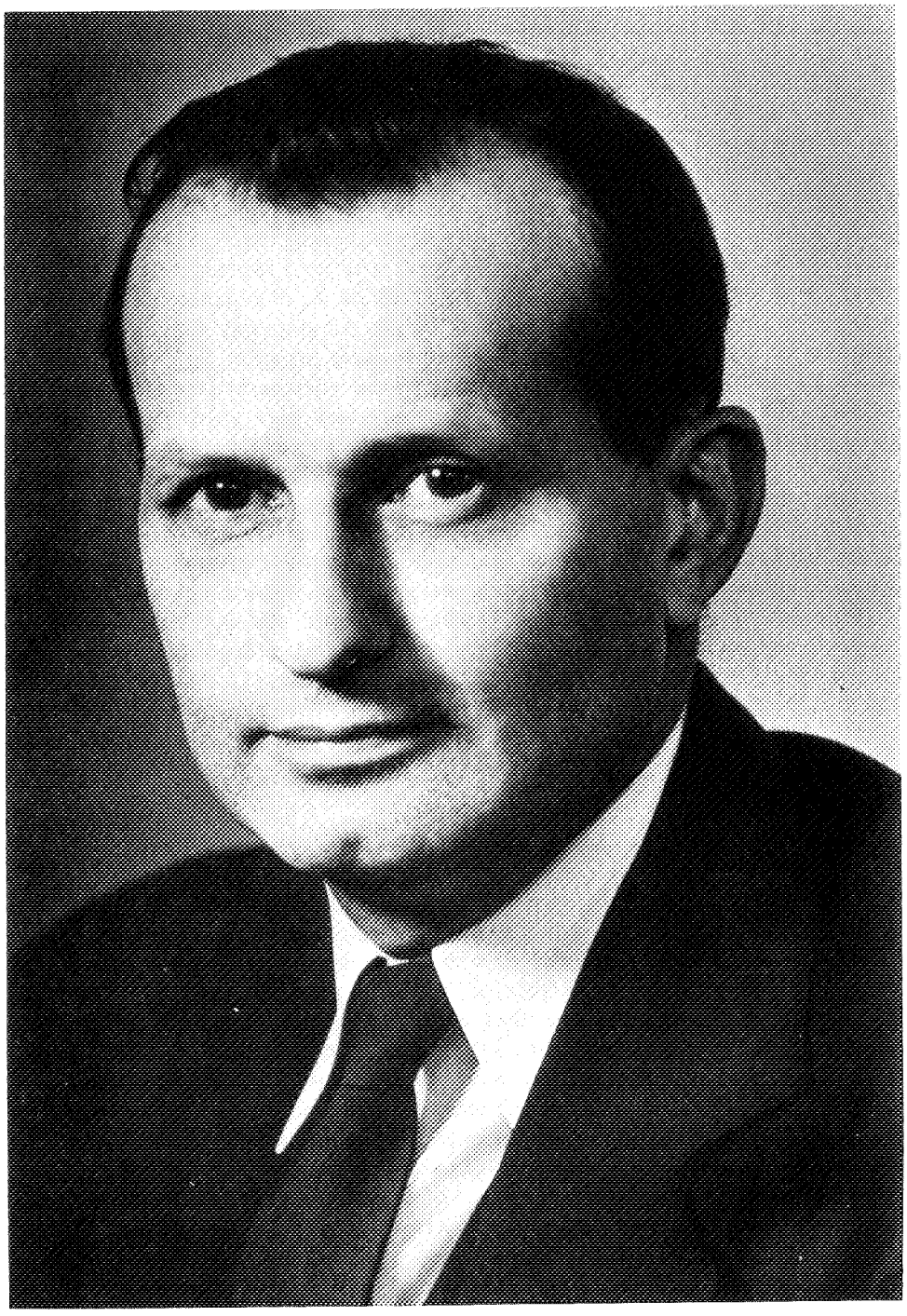

Fig. 11. Herrick Lee Johnston (1898–1965), scientist, educator, entrepreneur, and a pioneer in the science and technology of liquid hydrogen. (Courtesy of the Photo Archives, Ohio State University.).

In the 1950–1951 period, Johnston supplied the Los Alamos Scientific Laboratory with two hydrogen liquefiers. When the decision was made to conduct thermonuclear tests at Eniwetok, he was given the contract to reassemble the old Aerojet liquefier and add a second one. He chose Gwynne Wright to head the team to do this and the next two years became a period of swiftly moving activity for all of them. In May 1951, the first thermonuclear test, Operation Greenhouse, was successful and not long after it, preparations began for the next test. By late 1951, Johnston was so involved that he wrote to the president of Ohio State University requesting that: (1) his services to the university be reduced to 25 percent of full load, effective 1 January 1952; (2) selected members of the cryogenics laboratory be given leaves of absence; (3) OSU shop facilities be allowed to continue their work for Los Alamos; and (4) air and hydrogen liquefiers be made available for an essential training program. Johnston ended by assuring President Bevis that the university would be recompensed for its expenses and services. He was off and running again, doing very high priority work for the government, and the university had little choice but to go along with his wishes.[11]

In 1952, Johnston set himself up in business as the H. L. Johnston Company, Inc., and lured some of the key people from the OSU cryogenics laboratory. In May, the graduate school notified Mack that Johnston's name would be removed from the list of faculty approved to advise graduate students for masters and doctoral degrees. Mack protested vigorously, and in December he was joined by seven students who petitioned to retain Johnston as their preceptor. During this period, and working against odds, Johnston and his men delivered on their promise to produce deuterium on Eniwetok for the Mike Event of Project Ivy (fig. 12). On 1 November 1952, the event took place and was the first test of a thermonuclear "device"—a device that wiped out the islet where it had been set up. It was the most powerful explosion man had devised up to that time.[12]

National Cryogenic Engineering Laboratory

The development of the hydrogen bomb gave the National Bureau of Standards the opportunity to establish itself as the leader in cryogenic engineering research during the 1950s. The bureau had been involved with liquid hydrogen and cryogenic research since purchasing its first liquefier from the British Oxygen Company in 1904.[13] In 1925, Frederick G. Brickwedde became head of the cryogenic laboratory in the heat and power division, a post he held until 1957. He distilled liquid hydrogen to obtain a sample of deuterium for Harold Urey in 1931 (appendix A-3). In 1947, Brickwedde and William Gifford began a cryogenic engineering project. Some years earlier, Professor Samuel C. Collins of the Massachusetts Institute of Technology had designed a helium cryostat, which was being produced and marketed by the Arthur D. Little Company as the ADL-Collins cryostat. It had a capacity of about 4 liters of liquid helium per hour, which was ample for most university research needs, but Brickwedde wanted a cryostat of greater capacity. He and Gifford, working with the Arthur D. Little Company, designed one with a capacity five times greater than the ADL-Collins cryostat. It was placed into operation in 1952. From the summer of 1948, Brickwedde visited the Los Alamos Scientific Laboratory as a consultant. There he worked with Edward F. Hammel, head of the cryogenic laboratory, and E. R. Grilly. In 1949, Hammel began

Fig. 12. Dr. Herrick L. Johnston and staff who installed the cryogenic facilities at Eniwetok for Operation Ivy. Front row, L to R: Lester Cox, Ross Justus, Man Treziaki, Gwynne Wright, Herrick Johnston, Al Sesonski, Don McGill, Richard Reo, James Pierce; middle row: George Koch, Mike Nicata, Raymond Ward, Everett Allen, Paul Hansel, Nip Nunimaker, William Johnston, Richard White, Dewey Sandell: top row: Paul Camky, Charles Ames, Dave Wood, Howard Altman, Nate Hallet, Leon Wagner, Clarence Cunningham, _____ Groves, Douglas Chapin, Art Kurz, Jay Alberti. (Photo courtesy of James Pierce, identifications by Gwynne Wright.)

suggesting that the country needed a single large national laboratory for cryogenic engineering. He formed a committee of advisors on cryogenic engineering that included Manson Benedick, Brickwedde, Samuel Collins, Herrick Johnston, Earl Long, and Darrell Osborne. This group discussed Hammel's idea for a laboratory and supported it.[14]

The Bureau of Standards had become pinched for space in Washington and had decided to locate its expanding radio facility elsewhere. In 1949, the citizens of Boulder, Colorado, donated a 0.9-square-kilometer tract at the foothills of the Rockies for the facility. All these events might have remained unconnected except that Truman's decision to go forward with the hydrogen bomb put considerable support behind Hammel's suggestion for a cryogenic laboratory. The Atomic Energy Commission selected the Bureau of Standards to build and operate a cryogenic engineering laboratory at the Boulder site. In the summer of 1951, the Stearns-Roger Manufacturing Company began construction and within a year, two buildings were completed—one for the hydrogen and nitrogen liquefiers and another for research. Brickwedde and Gifford became the first members of the staff. By March 1952 liquid hydrogen was being produced and by August the laboratories were open.[15] The NBS-AEC Cryogenic Engineering Laboratory, with Dr. Russell B. Scott as its first chief, was in full swing in the fast-moving preparations for the hydrogen bomb development.

The gas liquefaction capacity was 350 liters per hour of liquid normal hydrogen (or 240 liters per hour of liquid parahydrogen) and 480 liters per hour of liquid nitrogen; storage capacity was 4500 liters of liquid hydrogen and 22000 liters of liquid nitrogen. It was the largest liquid hydrogen plant in the country and started operation less than three years after the Aerojet liquefier, built for hydrogen rocket experiments, closed down. By 1954, the Cryogenic Engineering Laboratory had an extensive program that included: (1) precise measurement of the thermal conductivities of metals and dielectrics, (2) mechanical properties of materials at low temperatures, (3) superinsulations, (4) high vacuum techniques, (5) transfer of liquefied gases, (6) development of vessels for storage and transport of liquid hydrogen, (7) ortho- to parahydrogen conversion, (8) hydrogen liquefiers and pilot plant evaluation, and (9) cryogenic testing, particularly with respect to vibration.[16]

Mobile Liquid Hydrogen Equipment, 1952–1954

The Air Force worked closely with the Atomic Energy Commission in hydrogen bomb development and as part of its responsibility, contracted for the development of mobile equipment. This work was cancelled in 1954, but not before some remarkable equipment had been built, which later became available for rocket research by the National Advisory Committee for Aeronautics.

One piece of equipment the Air Force developed was the air-transportable dewar for carrying liquid hydrogen or deuterium in the B-36 or B-47. The National Bureau of Standards and H. L. Johnston, Inc., both developed tactical dewars for the Air Force, and the vessels were described in a 1954 cryogenic engineering conference.[17] Essentially they utilized the same thermal insulation method as the familiar dewar vacuum flask, but the design was much more elaborate and complex in order to store liquid hydrogen at 20 K. The design minimized heat transfer by its three modes: conduction,

convection, and radiation. The liquid hydrogen was held in an inner tank. Surrounding it was a space evacuated to a high vacuum to minimize heat transfer by conduction and convection. The wall on the other side of the space was maintained at the temperature of liquid nitrogen, 77 K, which minimized heat transfer by radiation. The radiation shield—the walls of a liquid nitrogen container—was itself insulated from the outer shell of the dewar by another vacuum space.

The air tactical dewars held 750 liters of liquid hydrogen. The heat flow to the liquid hydrogen shell was slight, amounting only to about 4 watts; liquid hydrogen boil-off was about 7.5 liters per day, or 1 percent of rated capacity. The dewars were equipped with an array of valves, instruments, and a vacuum pump.

The tactical dewars (fig. 13) had to be built for rough treatment. The Johnston design employed hardened stainless steel rods to suspend the inner tanks and minimize conduction. These rods had to be tuned to an exact frequency to meet vibration and shock load specifications. Howard Altman solved this problem in an ingenious fashion typical of Johnston's operation. He calculated the required frequency and pitch and brought his violin to work one night to tune the rods; the Johnston dewar then passed its Air Force test. Several years later it passed another—unplanned—test. Altman was helping to unload it from a truck at the NACA Lewis Laboratory in Cleveland when it slipped and dropped four feet to the ground. He heard the rods vibrating sweetly, and the dewar survived undamaged.[18]

Another type of transportable dewar was fabricated by the Cambridge Corporation for the Air Force, using a design by the Arthur D. Little Company. Called the

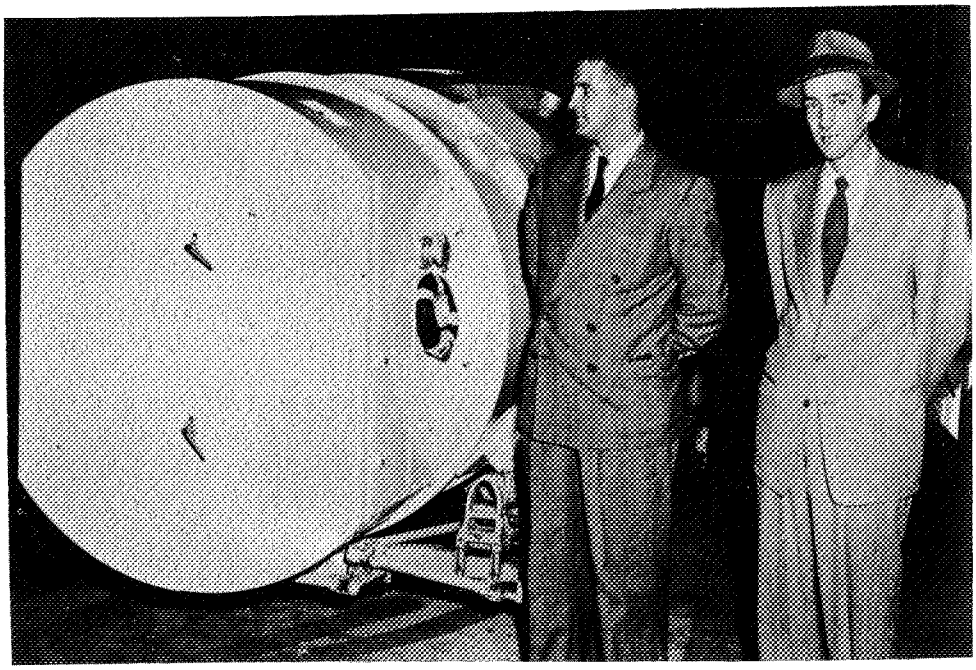

Fig. 13. Air-transportable dewar for 750 liters of liquid hydrogen developed by H. L. Johnston, ca: 1952. Howard Altman is on the left. (Courtesy of H. A. Altman.)

Refrigerated Transport Dewar, it used a closed cycle helium refrigerator, and the 2000 liters of liquid hydrogen could be stored or transported indefinitely with no loss as long as the refrigerator was operated. It was a large piece of equipment, occupying all of a 10.7-meter semi-trailer, and weighed 18.1 metric tons, including a diesel generator for refrigerator operation away from electric power lines.[19]

The third type of mobile equipment developed for the Air Force in the 1952–1954 period was a mobile hydrogen liquefier, again built by H. L. Johnston, Inc. It was mounted on three semi-trailers and was capable of producing 100 liters per hour of 45 percent liquid parahydrogen. Two of the trailers housed huge Norwalk horizontal compressors. The trailers also contained a gas holder and auxiliary equipment for the compressors. The third trailer housed the complete hydrogen purification and liquefaction equipment (fig. 14). All three trailers were capable of highway transport at 89 kilometers per hour. Gross weight was about 25 metric tons, and they required 105 kilowatts of electric power for operation.[20] The author remembers inspecting these trailers when they were loaned by the Air Force to the NACA (about 1956) and marvelling at how much equipment had been packed into such a small space. Particularly impressive were the big compressors with their large flywheels. Johnston's students had designed the layout of these trailers using cardboard cutouts to arrange the equipment. In their first operation at Kirkland Air Force Base, the whole 25-

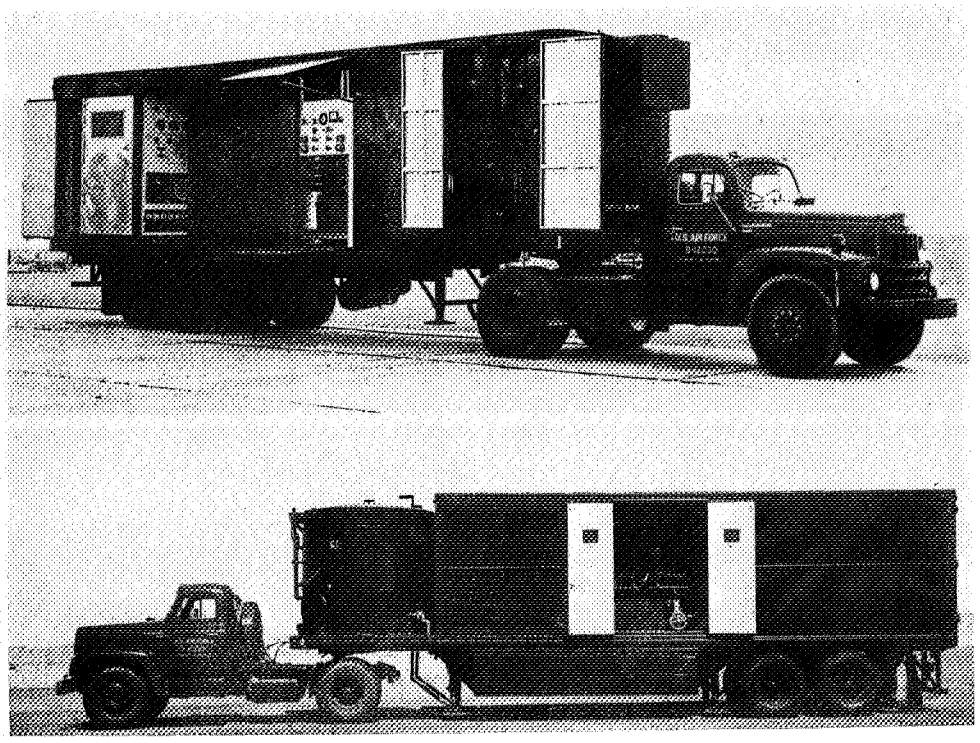

Fig. 14. Mobile hydrogen liquefier developed for the Air Force by H. L. Johnston, Inc., in 1952–1953. The lower trailer contains a gas holder and large compressor; the upper, hydrogen purifier and liquefier. (Courtesy of W.V. Johnston.)

metric-ton trailer began to bounce and "walk," moving 8 to 10 centimeters forward with each bounce—quite an awesome sight. The problem was solved by raising the trailer off its tires on large jacks.[21]

Cryogenic Information Exchange

With the fast-paced research and development in cryogenics that began in 1950, there was a need for exchange of information among the engineers and scientists engaged in the program. To that end, the NBS-AEC Cryogenic Engineering Laboratory sponsored an engineering conference at Boulder, 8–10 September 1954.[22] Sixty papers were presented on cryogenic equipment, instrumentation, insulation, and materials. A second conference, held in 1956, had fifty papers grouped into four categories—cryogenic processes, equipment, properties, and applications—and one special application, bubble chambers for research on the physics of particles. There were papers on the fundamentals of hydrogen liquefaction, ortho-to-para catalysts, distillation of hydrogen-deuterium mixtures, and safety.[23]

Among the papers in the third conference in 1957 was one by three Bureau of Standards men on the design of orthohydrogen-to-parahydrogen converters (the necessary step seen by Dwight I. Baker in 1949, p. 56.) The investigators reported that the 240-liter-per-hour hydrogen liquefier at the NBS cryogenic laboratory used 1.5 liters of 30–100 mesh granules of hydrous ferric oxide catalyst, and this converted the 240-liter-per-hour hydrogen output to about 94 percent parahydrogen. Another paper described liquid oxygen transfer equipment capable of 3800 liters per minute, developed by the Cambridge Corporation; while another described a 6000-liter liquid hydrogen dewar made by Beech Aircraft Company.[24] These papers illustrated the level of cryogenic and liquid hydrogen technology in 1957; a quantum jump had been made since the beginning of the decade. A fourth conference was held in Cambridge, Massachusetts, in 1958; the fifth at the University of California, Berkeley, in 1959; and the sixth back at Boulder in 1960.[25]

Summary

Under the stimulus of hydrogen bomb development, liquid hydrogen technology advanced rapidly in the first part of the 1950s. Hydrogen liquefier capacity had risen from the 80 liters per hour of the Aerojet plant in 1949 to the 350 liters per hour of the NBS-AEC Cryogenic Engineering Laboratory. The new national laboratory and the increased number of contractors who entered cryogenic engineering brought many new developments. Dewars were built that allowed as much as 6000 liters of liquid hydrogen to be stored indefinitely or transported cross-country. Applications of this cryogenic technology began to increase. Among them was the use of liquid hydrogen as a working fluid for nuclear rockets that began in 1955. The use of hydrogen in a nuclear rocket is not as a fuel, however; the energy comes from the reactor, and hydrogen is the ideal working fluid because of its low molecular weight. For this reason, the nuclear rocket development of the 1950s will not be discussed further except as it relates to technology used in the application of liquid hydrogen as a fuel.[26]